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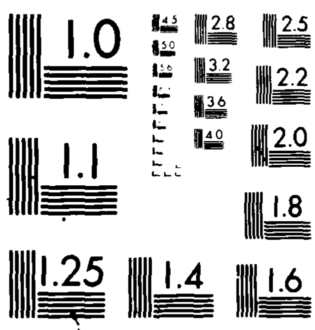

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REVIEW OF WEIGHTINGS FOR NUMBER OF OPERATIONS AND NIGHT OPERATIONS ON AIRPORT NOISE LEVELS

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AFAMRL-TR-81-12

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Henning E. von Gierke

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A search of the literature published from 1972 to 1980 was made to identify studies of the effect of now the number of aircraft operations and night weighting of sound levels affect human response. Significant articles are reviewed. Results are reported which show that a multiplier, K, of the logarithm of number of operations should be incorporated in cumulative noise measures. While some research suggests that K different from 10 could be used, analyses of the publications shows that next page

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setting K equal to 10 is equally valid within the confidence levels of the data.

No new data are available to support a change from the current night weighting of 10 decibels used in day-night average sound level (DNL). However, little scientific data to support this weighting exist.

Analyses are provided to examine the effect of setting K from 4 to 20 and of changes in night weighting on the area of airport noise contours. These analyses are reported as the ratio of contour area, at an equal decibel level, to the area when K equals 10 and night weighting is 10 decibels, for different classes of aircraft.

The conclusion of this study is that DNL is as good, or better, than other proposals to relate the noise from aircraft operations to community response, and should not be changed from its current definition.

PREFACE

This research was performed for the Air Force Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, Ohio, under Project/Task 723107, Technology to Define and Assess Environmental Quality of Noise From Air Force Operations. Technical monitor for this effort was Mr. Jerry D. Speakman of the Biodynamic Environment Branch, Biodynamics and Bioengineering Division.

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REVIEW OF WEIGHTINGS FOR NUMBER OF OPERATIONS AND NIGHT OPERATIONS IN AIRPORT NOISE LEVELS

1. INTRODUCTION AND RECOMMENDATIONS

Airport noise and community response have been under study for more than thirty years. International consensus is that community response to airport noise is related not only to the sound levels produced by individual airplanes, but also the number of operations that take place on an average day. Further, operations that take place at night are considered more onerous than those that take place during daytime. These factors are incorporated in day-night average sound level (DNL), introduced by the U.S. Environmental Protection Agency and used by the Air Force in community noise analyses since 1974. Over the past few years DNL has also been adopted by all federal agencies concerned about land use compatibility with respect to noise.

Notwithstanding the widespread adoption of DNL in the United States, the manner in which numbers of operations and night weighting of sound levels are accounted for continues to be a topic of study by scientists and administrators alike. The status of these studies up until 1974 are summarized in Ref. 1. The purpose of this study was to review the scientific literature between 1972 and 1980 with respect to these issues, and to evaluate the implications of recent research on possible changes in how numbers of operations and night weighting are considered in USAF aircraft noise analyses.

A critique of the most significant recent literature is contained in Section 2 of this report. An analytic investigation of the effect on DNL contour areas that would be introduced by changes in methods to account for numbers of operations and night weighting is provided in Section 3. Summaries of significant papers in the scientific literature and a bibliography of recent papers are contained in the Appendix.

Despite the continuing investigations, no compelling basis for changing the present form of DNL or its use in airport noise studies has resulted from recent studies. While more work has been done on exploring methods for accounting for numbers of operations, no justification has been presented to change from the physically sensible use of "energy" summation principles in DNL. On the other hand, very little new information has developed either to justify or to change the current procedure for weighting night operations. The choice of a 10 decibel weighting for sound levels that occur during the night, and indeed the choice of 2200 to 0700 for the definition of night, remains an administrative decision based largely on intuition rather than solid scientific foundation.

Recommendation:

The Air Force should retain the present procedure to account for number of operations (10 log N) and night weighting (+10 dB) expressed in day-night average sound level for the evaluation of community response and the assessment of land use compatibility with respect to aircraft noise.

2. CRITIQUE OF RECENT LITERATURE

2.1 Accounting for Numbers of Operations

Although there is generally universal agreement that the effects of sound level and duration of individual aircraft noise signals are interchangeable on an "energy" basis in judgements of annoyance, the extrapolation of this principle to the cumulative effect of a series of individual events remains a subject of investigation. The primary source of this concern lies in the inability of existing social survey data to resolve with any precision how the number of operations affects respondents' judgements of annoyance. With the exception of Rylander (see Appendix), investigators generally try to relate cumulative measures of the noise environment to average annoyance. The cumulative measures take the form of a measure of mean square sound level plus a term of the form K log N, where K is a constant to be determined, and N is the number of operations, plus constants. When K is equal to 10, the summation is on an "energy" basis. Some studies have also examined a summation of N without its logarithm.

The problem lies in the fact that the large variances in response data do not permit an inference of the value of K with any precision. For example, in the second survey around London's Heathrow airport, varying K from 2 to 22 made little difference in the analyses (see Ref. 1 for a summary). Recently, Fields (see Appendix) has examined the variability in various survey results, and has concluded that between uncertainties in the sound level measurements as well as responses, the 95 percent confidence intervals from 4 surveys would place K between -4 and 46! Schultz[2/], however, has shown a remarkable similarity in average judged annoyance between numerous surveys when he calculates the noise environment in terms of DNL, with K equal to 10.

On another tack, Rylander (see Appendix) continues to advance the thesis that annoyance increases with sound level, but not with number of events beyond 50 per day. The uncertainties in his sound level data and the small range of numbers of operations for the airports he examines restrict any comparisons of his approach to other airport situations. Further, his position is not supported by other studies.

In another effort to analyze social survey results to infer the value of K, Connors and Patterson (see Appendix) have reanalyzed their Tracor Surveys for NASA. They conclude that annoyance (expressed by a complicated scale) increases with the numbers of operations up to 100-199 per day, at which point it tends to decrease. Here, again, the very coarse stratification of sound levels in 10 decibel steps, the stratification of numbers of operations in coarse gradations, and the variances in judged average annoyance do not permit reliable discrimination. The authors do not attempt to combine sound levels and number effects directly, preferring to treat them as separate factors.

Since the surveys are so insensitive in determining K, several laboratory investigations have attempted to get at the problem directly. Rice (see Appendix) had subjects judge the annoyance of sets of aircraft flyover recordings during a series of test sessions in which both sound levels and the number of events per session were varied. He found that maximum sound level alone did not account for nearly as much of the variance in the judgements as was accounted for when both sound level and number of events were considered. In his analysis he explored the correlation between annoyance and cumulative sound measures incorporating sound level and an additive K log N term in which K was allowed to vary from 0 to 25. He found that a value of approximately 7 maximized the correlation; however, with K equal to 10 the difference was less than 0.01 in the correlation coefficients (0.9482 compared to 0.9286). One would be hard pressed to change from a K of 10 on this basis.

In a similar experiment Powell (see Appendix) tried the same approach to define K. Again, correlating to sound level alone accounted for about half the variance in judged annoyance. Adding a term of K log N improved the correlation to account for about 90 percent of the variance. Powell also attempted to optimize K, finding different values for A-weighted sound level and perceived noise level measures, with values from 14 to almost 20. Again, setting K equal to 10 for sound exposure level reduces the correlation coefficient by about one percent compared to his optimum K (0.95 to 0.94).

One can conclude that no work has yet been performed that would argue strongly that a value of K different from 10 is justified, at least for the usual case of average daily operations ranging from tens to thousands per day. However, it is as yet unknown what effect a small number of daily operations (with the concomitant long intervals between events) has on the validity of a cumulative noise measure such as DNL.

Most applications of average sound level around an airport are concerned with substantial numbers of events having generally high sound exposure levels. The average sound level produced by these events is usually sufficiently high that the presence of the other sounds in the environment, that is, the ambient noise due to other than the aircraft sounds, does not affect the numerical value for average sound level. At some combination of low number of events and sound exposure levels this assumption is no longer valid. For example, consider an ambient average sound level of 50 decibels. Adding one aircraft flyover per day with a sound exposure level of 85 decibels, or 10 per day at 75 decibels, barely affects the average sound level (an increase of 0.1 decibels). Yet, in both cases the flyovers are clearly detectable events. Are they disturbing? Are the two cases equivalent? Is the community response the same without one or both of the flyover cases as it is with their existence? According to the average sound level concept there is no difference in the three situations.

Social survey data reported in the literature[1/], while sparse for these conditions, do evaluate responses where the average number of events is as low as 6 per day, and the signal-to-noise ratio is of the order of 20 decibels or more above the ambient. Within the general variability of social survey data, average sound level fits the response data for this situation as well as it fits the data for larger numbers of events. Without sufficient data for fewer than 6 events per day one cannot really say how applicable the average sound level methodology is for one or two events per day, or for signals with lower signal-to-noise ratios. In a practical sense, however, such environments may disturb some people, but it is not likely that the average response of a group of people would be one of significant annoyance. In the absence of other data, it seems appropriate to use the average sound level concept with K equal to 10 even for situations involving only a few events per day.

2.2 Night Weighting

As different from the summation process in DNL for numbers of operations, which has a physical rationale and significant psychophysical justification, the night weighting of 10 decibels in DNL is largely based on intuition. Since the 1974 review in Ref. 1 a number of investigations of nighttime effects of sound have been completed, mostly related to surface transportation noise sources. The literature through April 1980 has been reviewed by Fidell and Schultz[3] and will not be reviewed again here.

In their critique of time-of-day weighting, Fidell and Schultz conclude that a rigorous scientific basis either for or against a time-of-day weighting did not exist, based on subjective response data. They do provide several qualitative arguments that support the utility of a night weighting. One is based primarily on the increased detectability of signals at night due to reduction in background sound levels. Another is based on the notion that since two to four times as many people are in residences during evening and nighttime, some weighting is warranted solely on the concept of an "equivalently impacted" population.

Fidell and Schultz go on to speculate that a night penalty can be justified on issues not related specifically to increased human sensitivity to sounds at night. If so, the magnitude of the weighting is probably of the order of 10 decibels, and that experiments to quantify it more precisely on the basis of human response are not likely to do so.

Arguments against night weighting are more strongly directed towards the arbitrariness of abruptly jumping from no weighting to a 10 decibel weighting on the stroke of a clock at 2200 hours. Despite the numerical simplicity of this approach, it clearly does not make sense in terms of human response. Yet, when alternate methods for phasing gradually into a night weighting were proposed by Galloway at a recent FAA/NASA conference on this subject[4], where airport and airline representatives were present, essentially no enthusiasm for these proposals was expressed, either for or against.

An important conclusion from the FAA/NASA conference was that it was not likely that any new research results could be expected in the foreseeable future that would improve the knowledge on night weighting effects. Therefore, the present weighting in DNL was probably as reasonable as any other. We agree with this conclusion.

It is worth noting that the magnitude, or even existence, of a night weighting for sound levels is not a major effect on most USAF analyses. Most USAF airbases have a very low percentage of their flight operations at night. It takes three percent of total operations at night to change a DNL value by one decibel over that with no night operations at all. With low nighttime operations, the magnitude of the night weighting is just not very significant for USAF flight operations. Where ground runup operations are extensive during both daytime and nighttime hours, however, the story could be quite different.

3.0 SENSITIVITY OF DNL CONTOURS TO UNCERTAINTIES IN SUMMATION FOR NUMBERS OF OPERATIONS AND NIGHT WEIGHTING

3.1 Generalized Expressions For Day-Night Average Sound Level

The expression for day-night average sound level (DNL) in decibels at any point in the vicinity of an airport, is:

$$L_{dn} = \overline{L_{AE}} + 10 \log_{10} N_{eff} - 49.4 \qquad (1)$$

where: L_{dn} = day-night average sound level

$\overline{L_{AE}}$ = mean square sound exposure level averaged over all operations

N_{eff} = effective number of operations

$49.4 = 10 \log_{10} \frac{86,400}{1}$ 86,400 is the number of seconds in 24 hours

The effective number of operations is the total number of operations during a 24-hour period, after multiplying the number that occur during the night by the night weighting. In the present standardized formulation[5/] the weighting is 10 times the number of nighttime operations, N_n, which are those occurring between 2200 and 0700 hours (10 p.m. to 7 a.m.). If a weighting other than 10 is used, the effective number of operations is the number that occur during the daytime, N_d, between 0700 and 2200 (unless some other time increment is specified), plus p times the number of night operations. That is:

$$N_{eff} = N_d + pN_n$$

Here "p" is determined by the magnitude of the night weighting. In the standard form for day-night average sound level p is equal to 10, corresponding to a 10 decibel night weighting on individual event sound exposure levels. In general, if the night weighting on sound level is W, in decibels, the value of p is determined by:

$$p = 10^{\frac{W}{10}} \tag{3}$$

Note that when W equals zero, p equals one, and the resultant summation of sound exposure levels over 24 hours is just the 24 hour average sound level, symbolized as 24 HL (also known as the 24-hour equivalent sound level). Table 1 summarizes various values that have been proposed in the literature for W and the concomitant value of p.

Table 1

Values For Operations Multiplier p Associated With Various Night Weighting Proposals

Night Weighting W in Decibels	Operations Multiplier p
0	1
5	3.16*
10	10
12	16.7
15	31.6

It is convenient to refer to day and night operations in terms of their fractions of the total operations during 24 hours. If

*a value of p equal to 3 is often used to approximate the multiplier for a 5 decibel weighting. When 3 is used, the actual weighting is 4.7 decibels.

f is the fraction of total operations that occur during the night, the effective number of operations, N_{eff}, can be expressed in terms of a multiplier times the total operations during 24 hours, N_T. That is:

$$N_{eff} = N_T [1 + (p-1)f] \tag{4}$$

The standardized method to account for the effect of number of operations in day-night average sound level assumes that sound level and duration of an event are exchanged on an equal energy basis. This assumption is accounted for in equation (1) through the use of mean-square sound exposure level for the total number of operations during a 24-hour period, and 10 times the logarithm of the effective number of operations. Some proposals have been made to sum operations on an other than energy basis. Most of these proposals assume a multiplier, K, times the logarithm of number of operations where K is different from 10.

These proposals arise from social surveys where subjective response is compared to calculated noise levels. The rather large variance in subjective response from most surveys has sometimes been used as a justification for attempting to fit the data with a value of K other than 10. (See Section 2 and Appendix of this report.)

Without regard here to the justifiability of the use of values of p or K different from 10, it is of interest to examine what effects non-standard K and p have on the size of contours of constant DNL. In order to explore these points, we define day-night weighted average operations weighted sound level, DNWKL, in which p and K are allowed to vary:

$$L_{dnpK} = \overline{L_{AE}} + K \log_{10} N_T[1+(p-1)f] - C \qquad (5)$$

where p and f are as defined above. Note that the constant to normalize the average sound level, over a 24-hour day, 49.4, which is 10 $\log_{10}$ (24x60x60), is no longer applicable if p and K are different than 10. In fact if they are different than 10, no obvious rationale for selecting C is apparent. Nevertheless, equation (5) provides a function with which the differential changes in contour areas can be examined for different values of p and K, if for this analysis, C is set equal to 49.4.

In the following discussion it is of interest to compare situations using the generalized day-night average sound level, with p and K not equal to 10, to the standardized DNL where p and K equal 10. Where DNL and L_{dn} are used without qualification, p and K are understood to be equal to 10. Where p and K are not equal to 10, the abbreviation DNWKL and the symbol L_{dnpK} will be used.

3.2 Relations Between Contour Area and Day-Night Average Sound Level

Despite the differences in runway configurations and flight paths from one airport to another, a simple functional relationship exists between DNL and the area enclosed by a contour of constant DNL. This empirical relationship was first developed by Galloway[6/] in terms of NEF for commercial aircarrier airports, and subsequently demonstrated for USAF airbases by Bishop, et al[7/]. For any specific airport, where detailed analyses of operations may provide a series of quite intricately shaped contours of constant DNL, regressions of DNL and contour area A in square miles take the general form

$$L_{dn} = a - b \log_{10} \frac{A}{1} \tag{6}$$

with squared product moment correlation coefficient (r^2) values between 0.992 and 0.999[7/]. The numerical values of "a" are dependent on the sound exposure levels of the aircraft involved and the number of operations. The value of "b" is dependent largely on the type of aircraft, e.g., trainer, fighter, transport, bomber, and only marginally on number of operations. (For a sample of 10 USAF airbases[7/], "b" has a value of 15.5, when averaged over all aircraft types, with a standard deviation of about ± 2.6. Note that the computations in Ref. 7 use the older form of SEL/distance function where duration adjustment in decibels is 10 times the logarithm of distance ratios. Where 6 times logarithm of distance ratio is used, as is currently incorporated in the SEL/distance functions, higher values of b can be expected to result, for the same operational situations, than with the older SEL/ distance functions.)

Equations (1) and (6) may be combined to obtain an expression for area, A, in terms of DNL, N_{eff}, the slope of DNL versus area, b, and an amalgamated constant, B. Thus:

$$A = 10^{\frac{(B + 10 \log_{10} N_{eff} - L_{dn})}{b}} \tag{7}$$

By analogy, a similar relationship between the area of a contour of DNL with arbitrary p and K can be posited:

$$A_{pK} = 10^{\frac{\left\{C + K \log_{10} N_T[1+(p-1)f] - L_{dnpK}\right\}}{b}} \qquad (8)$$

This expression will be used to explore the differential effects of variation of A with p and K, first with one held fixed and the other varied, then the reverse situation.

3.3 Variation of Contour Area With Non-Standard Summation Rules and Diurnal Weightings

3.3.1 Variation of Area with K, Holding p Fixed

First note that equation (8) may be rewritten as

$$A_{pK} = \left[10^{\frac{C}{b}}\right]\left[10^{\frac{K \log_{10} N_{eff}}{b}}\right]\left[10^{\frac{-L_{dnpK}}{b}}\right] \qquad (9)$$

Since we are interested in how area changes differentially as K changes, we can consider the derivative of A with respect to K, holding DNL fixed:

$$\frac{dA}{dK} = 2.3 \; A \left(\frac{\log N_{eff}}{b}\right) \qquad (10)$$

This expression is useful to indicate that an increase in K will increase the area of a specified DNWKL contour in direct proportion to the original DNL area for constant decibel values, the logarithm of the effective number of operations, and inverse proportion to the slope constant b. Although equation (10) may be used to estimate incremental changes in area for an incremental change in K, computations of such effects are as easily made with the exact expression for the ratio of area with $K \neq 10$, A_{pK}, to the area A with K = 10;

$$\frac{A_{pk}}{A} = 10^{\frac{(K-10)}{b} \log_{10} N_{eff}} \qquad (11)$$

For example, an increase in K from 10 to 15, with b equal to 15, increases the area of a fixed decibel value contour by a factor of 2.15 for 10 effective operations per day, 4.64 for 100 operations per day, and 10 for 1000 operations per day. Area ratios for effective operations per day between 10 and 2000, for area slopes b between 10 and 20, are plotted on Figure 1. Note that the calculations are plotted for constant values of (K-10)/b. Thus the same line on the figure will apply to the combination of K equal 15 with b equal 10 as applies to the combination of K equal 20 with b equal 20.

The effect of varying K from 4 to 20 is drastic, covering a range of 5 orders of magnitude. For a moderately busy Air Force base with 150 total operations per day, 5 percent at night, the area of a fixed decibel value contour varies at K equals 4, from 0.12 times the area when K equal 10, to 36 times that area when K equals 20, assuming b equals 15. With the same assumptions on K and b, the area ratios for a busy commercial airport with 800 total operations per day, 15 percent at night, range from 0.05 to 152.

An alternate way to visualize these effects is to consider how one would change the numerical values on an existing set of DNL contours if they were re-designated in terms of DN(10)KL. That is, the decibel change that would be attached to constant area contours for the identical set of operations. The incremental change in decibels to convert a contour designated in DNL to the DN(10)KL level in decibels for the same contour are listed in Table 2 for various values of K and effective

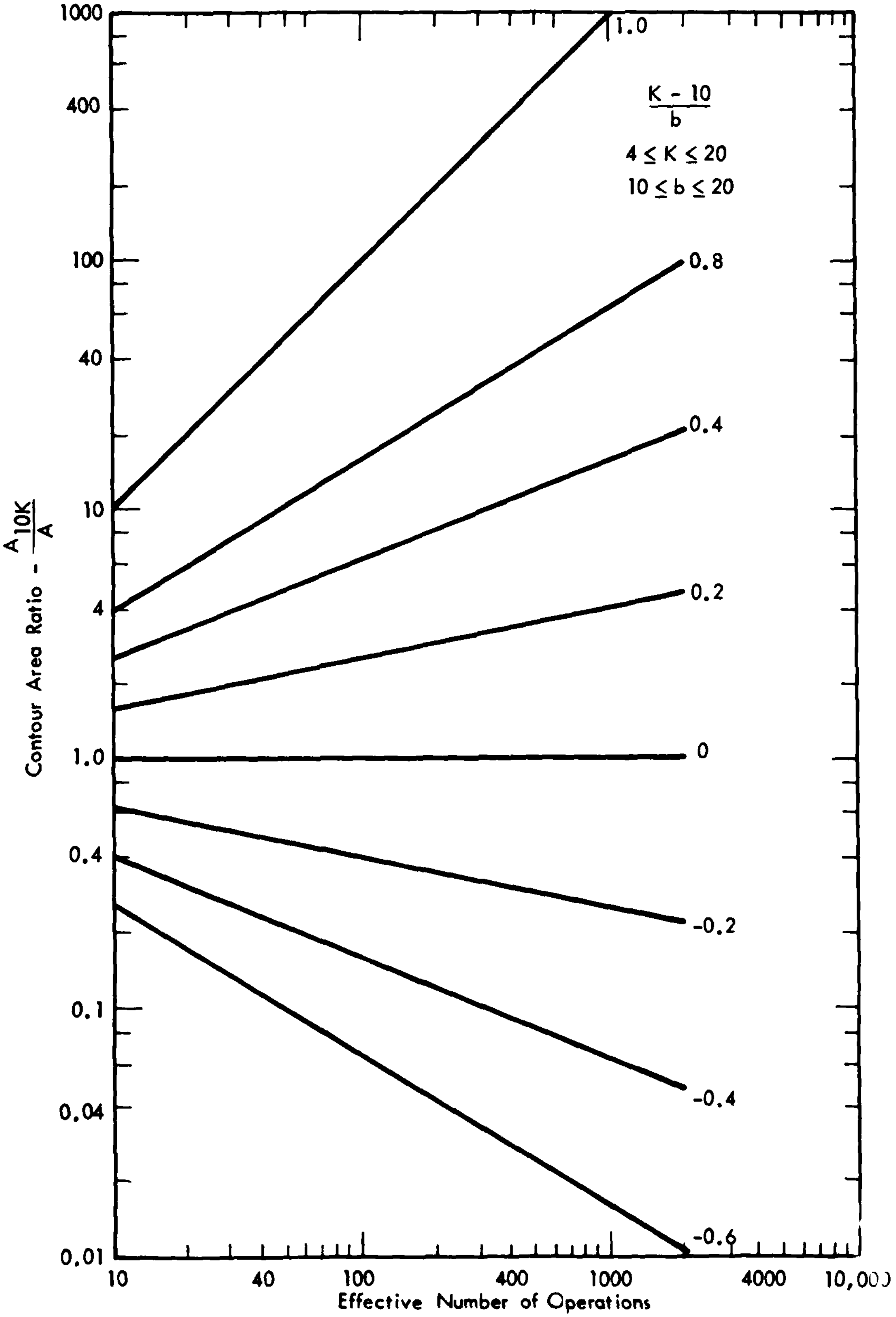


FIGURE 1. RATIO OF DNL CONTOUR AREA WITH $K \neq 10$ TO CONTOUR AREA WITH $K = 10$, $p = 10$

numbers of operations. As an example, consider 100 effective operations per day. With K equal 4, the numerical value for each contour is reduced by 12 decibels, 65 becomes 53, for example. With K equal 20, however, 65 is increased by 20 decibels, to become 85. For various values of K between 4 to 20 at 1000 effective operations per day, the range is from -18 to 30 decibels!

Table 2

Effect of $K \neq 10$ in Decibel Change
For a Contour of Fixed Area, re p = 10
$\Delta = (K-10) \log N_{eff}$

K	N=10	100	1000
4	-6	-12	-18
7	-3	-6	- 9
10	0	0	0
15	5	10	15
20	10	20	30

3.3.2 Variation of Area With p, Holding K Fixed at 10

In a similar fashion as above, the rate of change of area with a change in p, holding DNL fixed, is:

$$\frac{dA}{dp} = \frac{Af}{b} \frac{10}{[1+(p-1)f]} \tag{12}$$

The rate of change in area is again directly proportional to the original DNL area and inversely proportional to slope, b, but it is also directly proportional to the nighttime fraction of operations (as should be expected), as well as inversely dependent on the value of p itself. In this case, it is somewhat easier to visualize the effect of changes in p through the expression for the ratio of area, A_{p10} with $p \neq 10$ to the area with $p = 10$, A:

$$\frac{A_{p10}}{A} = 10^{\frac{10}{b} \log_{10} \frac{[1+(p-1)f]}{1+9f}} \tag{13}$$

Independent of number of operations and DNL, the ratio of areas increases as p is greater than 10, and decreases with p less than 10. For example, setting b equal to 15, assuming f to equal 0.15, setting p equal to 16.7, as in the original definition of Noise Exposure Forecast (NEF) computations, any DN(16.7)L contour is 1.27 times the area of a DNL contour of the same numerical value. On the other hand, decreasing p to unity as in 24-hour average sound level (equivalent sound level), with no nighttime penalty at all, would produce a contour having 0.57 times the area of a DNL contour of the same numerical value (only for f = 0.15, b = 15). Functions of area ratios for different values of f, relative to p equal 10, are plotted in Figure 2, 3, and 4 with b equal to 10, 15, and 20, respectively.

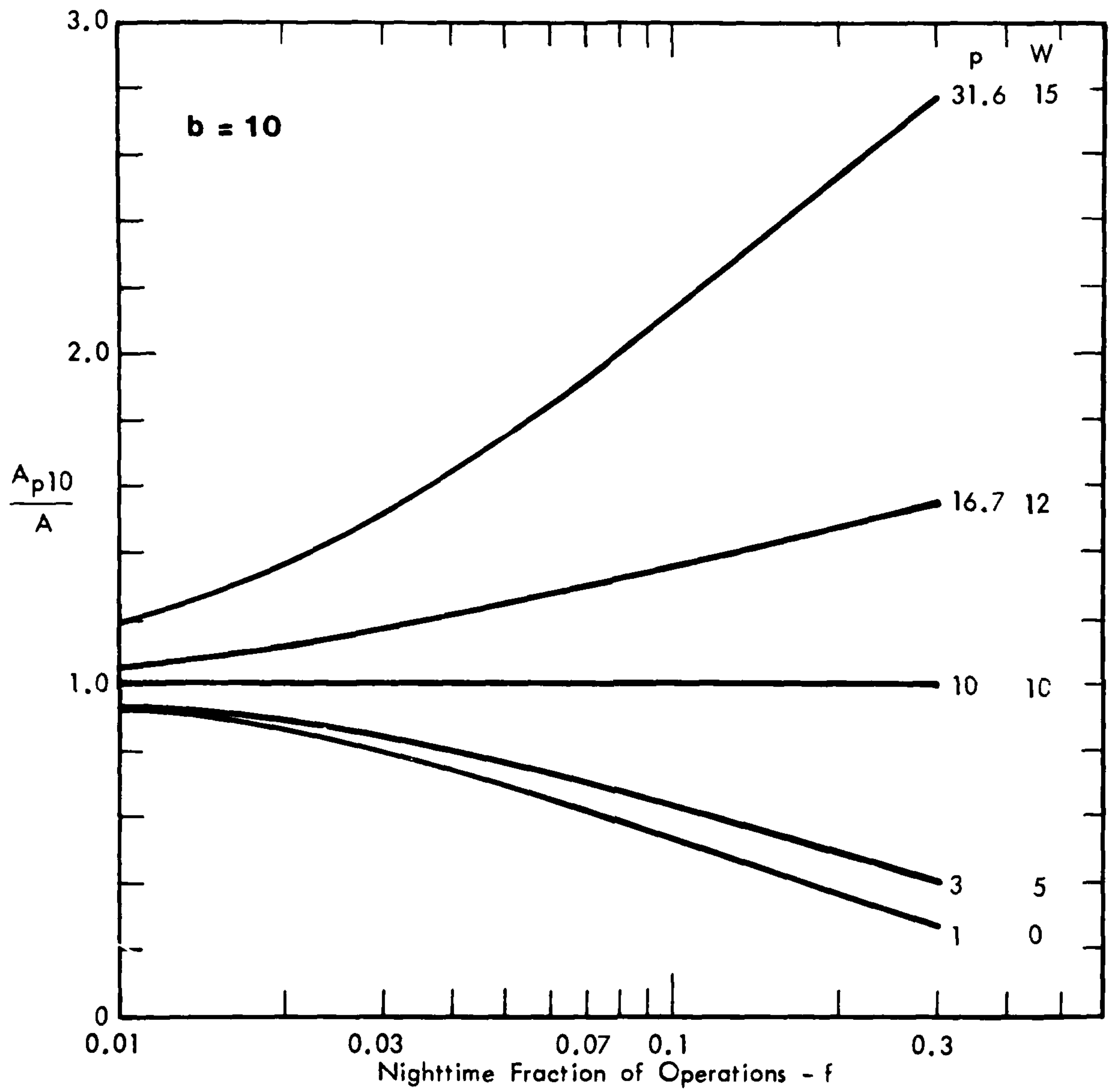


FIGURE 2. RATIO OF DNL CONTOUR AREA WITH NIGHT WEIGHTING W IN DECIBELS TO DNL CONTOUR WITH W =10 FOR b = 10 WHERE b IS CONSTANT IN DNL = a - b $\log_{10}$ AREA (sq.mi.)

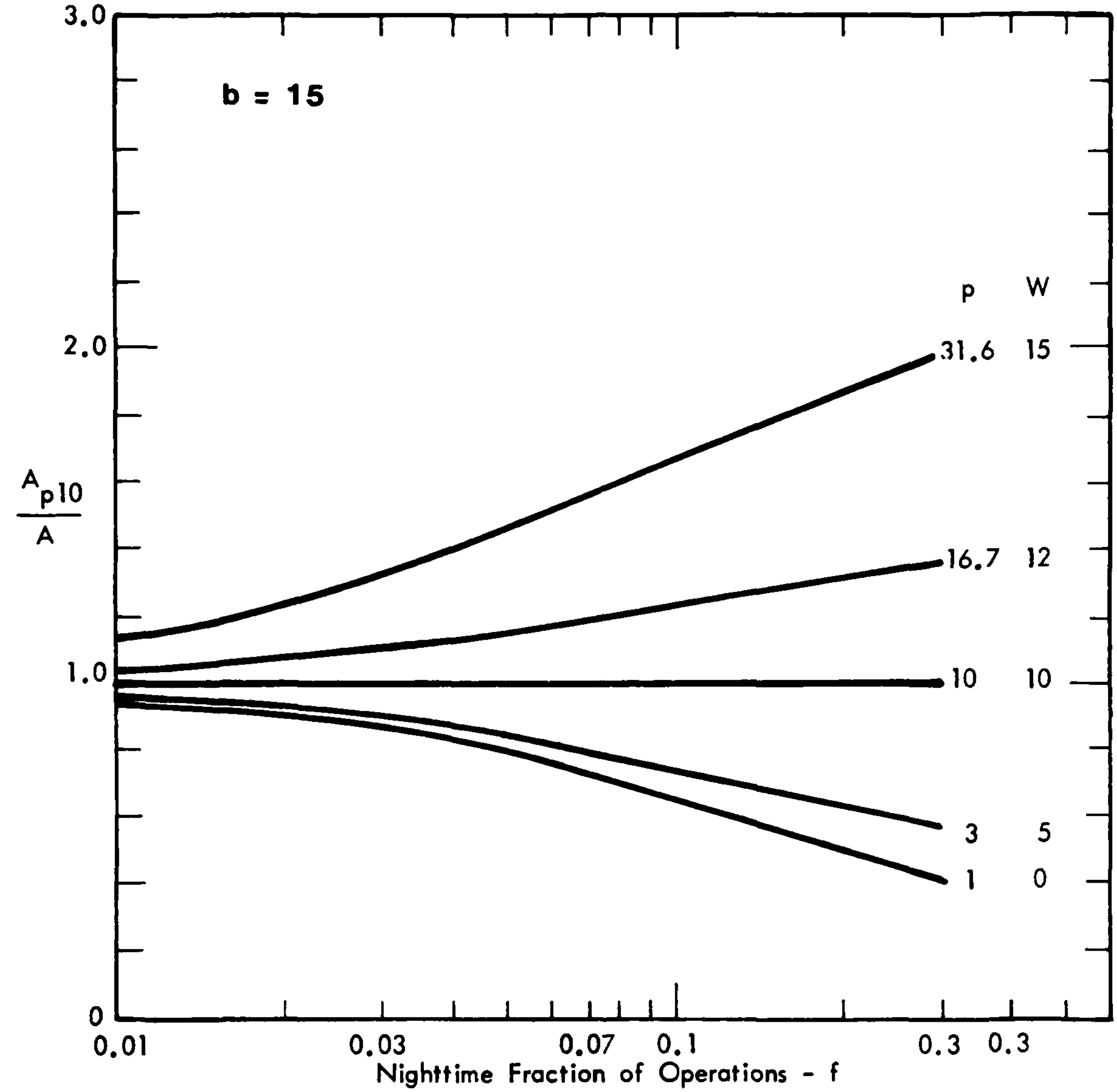


FIGURE 3. RATIO OF DNL CONTOUR AREA WITH NIGHT WEIGHTING W IN DECIBELS TO DNL CONTOUR WITH W = 10 FOR b = 15 WHERE b IS CONSTANT IN DNL = a - b $\log_{10}$ AREA (sq.mi.)

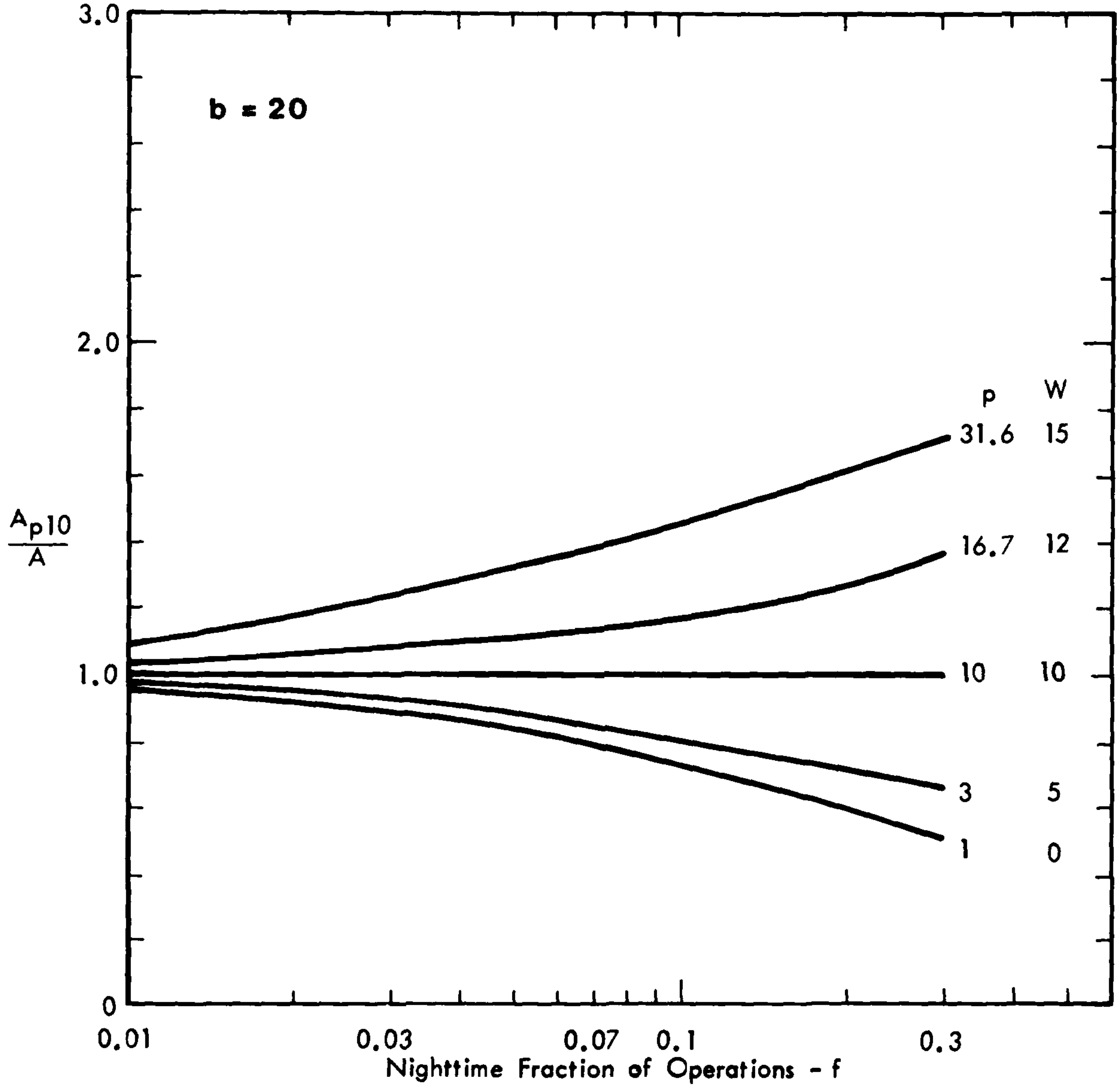


FIGURE 4. RATIO OF DNL CONTOUR AREA WITH NIGHT WEIGHTING W IN DECIBELS TO DNL CONTOUR WITH W = 10 FOR b = 20 WHERE b IS CONSTANT IN DNL = a - b $\log_{10}$ AREA (sq.mi.)

REFERENCES

1. Galloway, W. J., Community Noise Exposure Resulting From Aircraft Operations: Technical Review, AMRL-TR-73-106 (AD A-004822), Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, November 1974.

2. Schultz, T. J., "Synthesis of Social Surveys on Noise Annoyance," J. Acoust. Soc. Am., 64, 377-405 (1978).

3. Fidell, S., and Schultz, T. J., A Critical Review of Time-of-Day Weighting Factors for Cumulative Measures of Community Noise Exposure, BBN Report 4216 for the United States Environmental Protection Agency, April 1980.

4. Galloway, W. J., "Historical Development of Noise Exposure Metrics," Time-of-Day Corrections to Aircraft Noise Metrics, NASA Conference Publication 2135/FAA-EE-80-3, Langley Research Center, 1980.

5. American National Standard S3.23-1980, "Sound Level Descriptors for Determination of Compatible Land Use," Acoustical Society of America (1980).

6. Galloway, W. J., "Predicting the Reduction in Noise Exposure Around Airports," Proc. Inter-Noise 72, 356-361, 1972.

7. Bishop, D. E., Dunderdale, T. C., Horonjeff, R. D., and Mills, J. F., Further Sensitivity Studies of Community Aircraft Noise Exposure (NOISEMAP) Prediction Procedure, AMRL-TR-76-116 (AD A-041781), Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, April 1974.

APPENDIX

LITERATURE REVIEW
CAN K EVER BE ANYTHING OTHER THAN A PERFECT 10?

A continuing controversy exists over determining the most effective method of predicting annoyance due to aircraft noise exposure. As a consequence, the results from laboratory and social surveys are analyzed and re-analyzed in an effort to investigate the interaction and tradeoff effect between level of the aircraft noise events and the number of events per time period. The currently popular cumulative measure day-night average sound level (DNL) takes into consideration the noisiness characteristics of the aircraft flyover such as duration, spectral content and level, as well as the different numbers of events. While extensive research has focused on the different physical attributes of an aircraft flyover, it has been more difficult to identify the influence of the number of flyovers on annoyance. Consequently, there has been a variety of suggestions on the values and the methods to be used to account for multiple events within a given period of time.

Most of the investigations of aircraft noise exposure have resulted in a measure where noise level and number of events have been weighted with different constants. A general equation describing this relationship can be depicted as follows:

$$L_X = L + K \log N$$

where L_X is the total noise exposure as a result of some index or measure of magnitude of the noise L plus a term to account for overflight frequency where K is a constant and N is the number of overflights.

The value of the constant k in the above equation has most often been 10, however other values have been suggested as substitutes. This has usually been as a result of the investigator's interpretation of new noise survey data or closer scrutinization of previous survey data. Some researchers have gone further and recommended either the deletion of the number adjustment term, or a non-logarithmic form of the term. An extensive literature research was undertaken in an effort to assess the current status of this topic and the following articles were selected and analyzed as examples of attempts to resolve the controversy that still exists among some members of the scientific community.

Connor, W. K., and Patterson, H. P. (1976). "Analysis of the Effect of Numbers of Aircraft Operations on Community Annoyance," NASA CR-2741-N-76-30181B.

In this study, a re-analysis of social survey data from an earlier project for NASA, Connor and Patterson focused on the interaction between the number of aircraft overflights and the corresponding noise levels upon community annoyance response. Briefly, they concluded that rather than combine noise level and number of operations into one measure for predicting annoyance, it was better to consider them as individual variables to use to characterize community annoyance.

The data for this project were a re-analysis of the results from previous community noise surveys conducted by Tracor around nine U. S. airports during the period 1967-1971. The data base was comprised of questionnaire responses as well as the associated aircraft noise exposure information. The noise data for these nine studies were reported in terms of CNR, which accounts for number of operations with a 10 log N model.

Connor and Patterson were interested in testing the validity of this equivalent energy model, as well as alternative models such as the "dB(A) peak" concept or Swedish model as proposed by Rylander et al. (Rylander, 1980). In order to facilitate this, they transformed Rylander's results, which were in the form of "dB(A) peak," into "largest PNL" by the approximation $PNL \approx L_{Amax} + 13$ dB. They defined "largest PNL" as the highest value of PNL associated with an aircraft type that had at least three operations at an airport within 24 hours. This was the same as Rylander's definition of "dB(A) peak" used in his model of annoyance prediction. Given this data transformation, it was then possible to compare the Rylander results with the NASA study. The NASA study response data were also related to sound levels expressed as energy mean PNL (PNL). These data, when combined with the number of daily operations, were used to compute predicted annoyance in terms of the equivalent energy method.

The subjective response data to the aircraft noise exposure were derived from questionnaires. The annoyance information from these questionnaires was reported in terms of an "Annoyance G" scale which was a complicated assessment of "annoyance caused through activity disturbance" (McKennell, 1970). Herein lies some of the major problems with this study. The authors admit that there is a wide variation in the annoyance scores at any given exposure level, and further the distribution of the scores is not consistent. Therefore, in order to compare these results with Rylander's study, Connor and Patterson arbitrarily selected some point on their "Annoyance G" scale beyond which they determined that the respondent could be said to be "very annoyed" or "highly annoyed." After defining what they considered to be "very annoyed," they then generously assumed that the responses from their study were approximately the same as the responses obtained by Rylander in which he directly asked if the observer was "very annoyed." It is difficult enough to assess people's annoyance response given a direct question; but the researchers risk reaching misleading conclusions when after assigning their own response labels to respondents answers they then attempt to make inter-survey comparisons.

Compounding the problem of response variability was the fact that Connor and Patterson also categorized the independent variables, number of operations, and noise levels into class intervals. They felt that they could achieve a meaningful description of

"Annoyance G" for various exposure combinations (noise plus level combinations) with this type of categorization. Their rationale for the class intervals was somewhat forced because it was determined partly according to the overall distribution of respondents in the survey sample and partly for convenience in evaluating the noise prediction models. As a result, the noise levels were divided into 10 dB intervals with 110 and 80 PNdB as the upper and lower limits, respectively. The number of aircraft operations, on the other hand, were divided into intervals of 50 (50-99), 100 (100-199), and 200 (200-399) events. Less than 50 operations or more than 400 operations per day were the lower and upper limits of the operations category.

In accordance with the equivalent energy model, each time the number of operations doubles there is a corresponding increase in average sound level of 3 dB. Thus, the difference in decibels between the number of operations intervals is approximately 3 dB. Connor and Patterson claimed that if the equivalent energy model were effective in predicting annoyance responses, there should be a 6 dB difference between the response curves graphically depicting the operational intervals of N = 50 - 99 and N = 200 - 399. This lack of separation is not necessarily due to any deficiency in the energy principle but rather can be related to the high degree of subjective response variability and arbitrary grouping of the data.

Connor and Patterson also concluded from this research that Rylander's "peak dB(A)" concept was not an adequate model for predicting annoyance, at least with these data. Contrary to Rylander's Swedish model, these authors found that annoyance increased with the number of operations beyond 50 overflights per day to a point where the number of operations reached

N = 100 - 199 per day. At this threshold, a decrease in annoyance response was observed. This seeming decrease in annoyance could be interpreted to mean that the number correction term 10 log N, which provides an additive adjustment in the equivalent energy model for increased number of events, would also be inappropriate.

These conclusions must be viewed in the context of this experimental research project. There were several problems, some already mentioned, that confounded the trade-off effect between noise level and number of operations. In addition to the grouping of noise level and operational data and the high degree of variability in the human response data, there were also differences in acoustical measurement methodology over the different sites. There were seasonal differences and lack of availability of detailed operational data correlated to noise level information. Thus, before the concept of equivalent energy and the number correction term 10 log N can be dismissed, it would be necessary to have a study which clearly controls these variables.

Rice, C. G. (1977). "Investigation of the Trade-Off Effects of Aircraft Noise and Number." Journal of Sound and Vibration, 52(3), 325-344.

In this laboratory study, Rice was concerned with investigating the validity of Rylander's "peak dB(A)" (Rylander, 1980) concept as well as exploring other aspects of the trade-off effect of the number of aircraft operations and noise exposure level. There were 25 aircraft noise exposure conditions: (1) 5 rates of aircraft events (4, 8, 16, 32,64) per hour combined with (2) 5 different noise levels (45, 55, 65, 75, 85 dB(A)). The annoyance response to the noise exposure was obtained by having the observers answer a short questionnaire. The various noise measures that were examined for their ability to predict annoyance ranged from single-event measures that only accounted for level (peak dB(A), average peak dB(A)); measures that incorporated both level and duration (average peak PNL, average peak EPNL, L_{eq}); measures that accounted for level, duration, and number of events (NEF, CNR, NNI, NPL); and measures that only considered number of events (N, log N).

Once again, the results did not support Rylander's peak level theory. It was evident from the results of Rice's study that those measures that incorporated level, duration, and a correction for number of events were the most effective predictors of annoyance. Thus, L_{eq} and NEF appeared to be the best all-over measures for predicting annoyance with mean correlation coefficients of r = .95 compared to the "peak dB(A)" concept or the Swedish model of r = .93.

Rice also examined the effect of the addition of number correction terms either K log N or N/K to three single-event measures. In the process, he varied the value of the constant K in order to determine the optimum value. The three measures were average peak EPNL, average peak dB(A), and average peak PNL. The results of this study showed that the annoyance predictions for these three measures improved for the most part with the addition of a number correction term.

Using K log N as the independent variable, Rice increased the multiplier K from 0 to 25. The highest correlation coefficient was found for K = 7. This was defined by Rice as the optimum value for K. However, it was noted that the differences among the correlation coefficients for different values of K, when compared to 10 log N, were on the insignificant order of .001 to .014 for the above three measures. Rice admitted that the value of K could vary enormously without having a significant effect.

Multiple linear regressions were also performed by using number divided by a constant (N/K) rather than log N as the additional independent variable with the same three noise metrics. As with the addition of log N, the addition of N/K improved the annoyance prediction capability of these measures. A comparison of the correlation coefficients for the 10 log N and N/6 (the optimum value for the K factor in this term) data revealed a .01 difference. This was a slight but insignificant indication that level plus number correlates better with annoyance than level plus log number. Rice also pointed out that for either form of the number correction terms (K log N or N/K) the optimum value for K is relatively insensitive to change. Based upon this evidence, it would be very difficult indeed to say with any conviction that K should be any value other than a perfect 10.

Fields, J. M. (1980). "The Relative Importance of Noise Level and Number of Events on Human Reactions to Noise: Community Survey Findings and Study Methods." NASA Technical Memorandum 81795

This was one of the latest research projects to come under the category of re-analysis of previous noise survey data. Fields attempted to quantify the uncertainties in determining the trade-offs between the sound level of individual events and the number of those events by inference from survey response data. In essence, his analysis merely reaffirmed the widely accepted assumption that annoyance is directly related to a logarithmic transformation of the number of noise events; thus, one more blow to the Swedish model theory (Rylander 1980).

In the seven studies that he reviewed, including five for which he actually re-analyzed the original data on the NASA Langley computer, he concluded that the number of noise events was related to annoyance. Therefore, some form of a number correction term must be included when predicting annoyance. Fields analyzed four surveys (Heathrow 1961, 1967, 1976, and his own 1979 railway study) in order to more precisely define a value for the constant K in the correction term K log N. He found that the values for K ranged from 1 to 24. However, more importantly, the 95 percent confidence interval for these values ranged from -4 to 46. At the same time that Fields concluded that the value of K is probably less than 10 he also cautioned that the trade-off estimates are undoubtedly biased by unknown noise measurement errors.

This project affords a good review of some of the more notable noise surveys, and he makes suggestions on approaches to be used if new studies are to be performed. However, the evidence is not strong enough to advocate changing K from other than a perfect 10.

Kuwano, S., Namba, S., and Nakajima, Y. (1980). "On the Noisiness of Steady State and Intermittent Noises," Journal of Sound and Vibration, 72(1), 87-96.

This laboratory experiment by Kuwano et al. was designed to evaluate the judged noisiness of intermittent and steady state sounds. It was concluded that noisiness can best be estimated by using a cumulative noise metric with the addition of the number correction term K log N. This study investigated the effects of sound level (dB(A)), the effects of number of single events (N), the effects of level of total energy (duration plus sound level), and the effects of mean energy level (dB(A)) on the subjective evaluation of noisiness of steady state and intermittent noises.

The results of this study showed that judged noisiness did not exhibit a high correlation with mean energy level or 10 log N when compared individually. However, when both components were used together in a new measure called L_n, there was a high correlation coefficient of $r = 0.904$.

Kuwano joined the ranks of Rice and others in the eternal quest to increase the precision of the number correction term by changing the value of the constant K in the term K log N. However, unlike Rice et al. (Rice, 1977), Kuwano concluded that both the correlation coefficient and the rms value resulting from a difference in the K value were very sensitive to change. However, it can be noted that there was a decided difference between the signals used by Rice and those used by Kuwano. Rice employed recordings of aircraft flyovers and Kuwano did not. Further, the exact spectral content of Kuwano's signals cannot be determined from this report of his experiment.

The intermittent signals in Kuwano's experiment were all 1 second or less in duration which did not compare to the duration of the aircraft overflights used by Rice. Perhaps these differences as well as others, by Kuwano's own admission, lead him to conclude that the value of K is sensitive to change.

Kuwano reasoned that the factor K is maximized when both the correlation coefficient is high and the rms value is at a minimum. Using this criterion, he concluded that 10.12 to 10.23 were the optimum values for K for all 38 stimuli. In fact, Kuwano found there was no significant difference in the respective correlation coefficients and rms values when K was any of the corresponding optimum values, or even a perfect 10.

Powell, C. A. (1980). "Annoyance Due to Multiple Airplane Noise Exposure," NASA Technical Paper 1706.

One of the more recent laboratory tests designed to investigate the annoyance effects of multiple aircraft overflights was conducted at NASA Langley by C. Powell. The primary aim of the study was to examine more closely the interaction effects of the number and level of flyovers on annoyance. In conjunction with this purpose, Powell also reported on the applicability of the "equivalent energy" and the "dB(A) peak" concept as noise measurement models for predicting annoyance due to aircraft noise exposure.

Powell used five recordings of Boeing 727 aircraft takeoff noise signals as the stimuli. The number of overflights (1, 3, 5, 9, 17) and the sound levels (56, 62, 68, 74, 80 dB(A)) during any given session were combined in a factorial design and balanced for order of presentation such that each observer made judgements on five level-number conditions.

The test observers indicated their annoyance response by filling out a short questionnaire during each testing session. Most of the questions were designed on the order of a 10 point numerical scale, ranging from zero as "not at all annoyed" to 10 as "extremely annoyed."

In order to explore the relation between number of events and noise level as typified in a cumulative noise index, Powell evaluated the ability of several measures to predict annoyance both with and without the inclusion of a correction term for number of events. He also attempted to determine the optimum value for the constant K in K log N by varying the values in combination with different noise measures.

The results from Powell's study were for the most part within the realm of previous research which has focused upon the noise and number controversy. He found that annoyance judgements increased in a linear fashion with increased noise level. Additionally, his results failed to provide substantial evidence for Rylander's (Rylander, 1980) "dB(A) peak" concept that annoyance does not increase above a certain number of aircraft operations. Powell demonstrated that the addition of a number of events adjustment term to a single-event noise measure accounted for approximately 90 percent of the variances compared to only 50 percent of the variance when only sound level alone was assessed. Thus, the total number of aircraft operations, as well as sound level, had to be taken into consideration in determining an effective measure of annoyance.

Powell attempted to calculate what he termed the optimum value of K and found that it was somewhat dependent upon the noise metric. The values for K varied from 14 to 19.3, which tended to be higher and differed from the traditional values assigned to K of 10 or 15. This is the point where Powell's conclusions seem initially to deviate from the norm. However, upon closer examination of the data and by his own admission the correlation coefficient near the optimum value of K varies insignificantly. This means there is a small difference between the correlation coefficients associated with the number correction factor K as related to annoyance and number of flyovers. For example, Powell concluded that for sound exposure level (SEL), the optimum value for K would be 14.0 with a 95 percent confidence interval of ±3.7. This confidence interval thus indicates that K may vary from 10.3 to 17.7. The associated correlation coefficients for these three values (14.0, 10.3, 17.7) of K were approximately r = .951, .944, and .94[illegible], respectively. These correlation coefficients differ at the most by .01. With such a small difference, it would be impossible to detect the effect of changing K from 17.0 to 10.0 on this measure's ability to estimate annoyance.

Powell also examined the laboratory response questionnaire data in order to determine subjective annoyance to aircraft noise exposure at different times of the day. The results from his "home-projected" questions ("How annoying would the noise be in your home?") indicated that the time-of-day weightings in such measures as DNL are still appropriate. Powell recommended an evening weighting of 5 dB (much like California's community noise exposure level CNEL). However, he was unable to establish one number as the night weighting but rather indicated a range for the weighting constant of 8 to 15 dB depending upon the sound level. Without a more detailed study to include a wider range of levels, a night weighting other than 10 is not recommended.

This study has very carefully dissected the relationship between number of aircraft operations and the relative noise level as variables in affecting annoyance judgements. However, the evidence is not conclusive enough to support a determination for K other than a perfect 10.

Rylander, R., Bjorkman, M., Ahrlin, U., and Sorenson, S. (1980). Aircraft Noise Annoyance Contours: Importance of Overflight Frequency and Noise Level. Journal of Sound and Vibration, 69(4), 583-595.

Some of the most controversial conclusions about the effect of number of aircraft operations and noise level on community annoyance have been produced by Rylander et al. Based on the results from several original noise surveys conducted in various countries and the re-analysis of the results from other surveys, Rylander has developed a descriptor of aircraft noise exposure that has been referred to as the Swedish model. According to the proponents of this theory, if there are more than 50 operations per day then the most important parameter for predicting annoyance is the "peak dB(A)" level of the noisiest type of aircraft. Of course, there are certain limitations which must be adhered to before this simplistic approach can be utilized.

In this latest paper advocating the Swedish model approach, the authors have been able to derive a mathematical expression for predicting the proportion of people who would be "very annoyed" if the number of aircraft flyovers was between 35 and 50 operations over 24 hours. The first limitation to be noted is that only the aircraft overflights above 70 dB(A) are counted in computing the total number (N) of aircraft. In addition, the "peak dB(A)" sound level is based upon the level from the noisiest aircraft type which occurs at least three times during 24 hours. Given these limitations, the equation is as follows:

$$a = L_{Amax}(0.0664N - 1.8245) - 4.2299N + 112.263.$$

Nine airports were involved in these surveys, with a total of 38 investigation areas where 3746 persons were interviewed. While the number of conducted interviews might have been impressive, the fact that there was a paucity of actual noise measurements taken was not. The noise level predictions for the different types of aircraft were based upon nominal noise contours. A limited number of sound level measures were made in the areas estimated to be within the 70 and 90 dB(A) contours.

Rylander based his conclusions upon data from only 23 areas with L_{Amax} values of 70 $\pm$ 2, 80 $\pm$ 2 and 90 $\pm$ 2 dB(A). He reported that, regardless of level, in areas with less than 35 overflights per day, only 10 percent of the people interviewed expressed that they were "very annoyed." Whereas in areas exposed to about 50 overflights per day the extent of "very annoyed" was more dependent upon the noise level of the exposure area. The reported annoyance was low for the 70 dB(A) area and increased in the 80 and 90 dB(A) area; and, in fact, there was no further increase in annoyance due to increased number of operations up to 150 events per 24 hours. The applicability of these conclusions must be viewed with caution because it is quite obvious to us that a very low number of overflights at extremely high levels would be assessed as annoying by a large percentage of the population.

On the basis of the conclusions reached from this report, Rylander et al. point out that in areas of high aircraft operations (200 or more) there is nothing to be gained by reducing the number of operations to 150. Rather, the noise levels from the noisiest aircraft type should be reduced by 5 dB(A) to achieve a decrease in annoyance. Therefore, measures based on equal energy principles are not recommended because they do not represent the real correlation between noise exposure and annoyance.

While the Swedish model presents a spicy alternative to contemplate, the high degree of variability in judgement response data along with the lack of rigor in actual field noise measurements points up uncertainties in this prediction method. The validity of the "dB(A) peak" principle has yet to be verified by other independent research. On the contrary, most other research does not support the "peak dB(A)" concept. Instead, it has been found that in order to account for the variance associated with predicting annoyance it is necessary to have some measure of cumulative noise in combination with a correction term such as K log N for the number of aircraft operations. These studies have shown that there already exists a high correlation between number of aircraft events and noise level and expected community response. The difficulty is in determining whether there is a significant increase in the correlation coefficient due to a modification in the constant K from 5 to 10 or 15; and, even if it were so, have other independent studies concluded that the optimum value for K should be other than a perfect 10? The answer is no.

BIBLIOGRAPHY

Alexandre, A. (1974). "Decision Criteria Based on Spatio-temporal Comparisons of Surveys on Aircraft Noise." Noise as a Public Health Problem (ed. W. D. Ward), 619-626.

Borsky, Paul N. (1977). "A Comparison of a Laboratory and Field Study of Annoyance and Acceptability of Aircraft Noise Exposures." NASA CR-2772.

Connor, W. K., Patterson, N. P. (1976). "Analysis of the Effect of Number of Aircraft Operations on Community Annoyance." NASA CR-2741-N-76-30181 B 73, 1-53.

Edwards, R. M. (1975). "A Social Survey to Examine the Variance of Aircraft Noise Annoyance." Journal of Sound and Vibration, 41(1), 41-51.

Fields, J. M. (1979). "Railway Noise and Vibration Annoyance in Residential Areas." Journal of Sound and Vibration, 66(3), 445-458.

Fields, J. M. (1980). "The Relative Importance of Noise Level and Number of Events on Human Reactions of Noise: Community Survey Findings and Study Methods." NASA TM-8175.

Hall, F. L., Tayler, S. M. (1979). "Predicting Community Response to Road Traffic Noise." Journal of Sound and Vibration, 52(2), 1-13.

Hiramatsu, K., et al (1978). "A Procedure for Rating Fluctuating Noise on the Basis of the Additivity of Annoyance." Journal of the Acoustical Society of Japan, 34(11), 650-658. Jap/Eng. abstract.

Johnson, G. W., Caruthers, R. (1974). "Urban Traffic Noise Annoyance Measurements and Derived Indices." Research Report No. 24. Joint Program in Transportation at the University of Toronto and York University.

Kuwano, S., Namra, S., Nakajima, Y. (1980). "On the Noisiness of Steady State and Intermittent Noises." Journal of Sound and Vibration, 72(1), 87-96.

Leonard, S., Borsky, P. N. (1973). "A Causal Model for Relating Noise Exposure, Psycho-social Variables and Aircraft Noise Annoyance." Proceedings of the International Congress on Noise as a Public Health Problem, pp. 691-705. Dubrovnik, Yugoslavia, 13-18 May 1973.

McKennell, A. U. (April 1963). "Aircraft Noise Annoyance Around London (Heathrow) Airport." London, Central Office of Information.

McKennell, A. C. (1970). "Noise Complaints and Community Action." Symposium on Acceptability Criteria for Transportation Noises, J. D. Chalupnik, ed., University of Washington Press, 228-244.

McKennell, C. (1977). "Community Response to Concorde Flights Around London (Heathrow) Airport." Social and Community Planning Research, London.

National Research Council, National Academy of Sciences, Washington, D. C. (1977). U.S.A. pp. 1-17. "Community Reactions To Concord: An Assessment of the Trial Period at Dulles Airport."

Powell, Clemans (August 1980). "Annoyance Due to Multiple Airplane Noise Exposure." NASA TP 1706.

Rice, C. G. (1977). "Development of Cumulative Noise Measures For the Prediction of General Annoyance in an Average Population." Journal of Sound and Vibration, 52(3), 345-364.

Rice, C. G. (1977). "Investigation of the Trade-off Effects of Aircraft Noise and Number." Journal of Sound and Vibration 52(3), 325-344. 1977.

Robinson, D. W. (April 1977). "Practice and Principle in Environmental Noise Rating." Pp. 24, National Physics Laboratory, Teddington, England. N78-23885/4GA (No. 18,1978).

Rohrman, B. R., Finke, M. D., Guski, R., Schumer, R. and Schumerkohrs (1974). "An Interdisciplinary Study on the Effects of Aircraft Noise on Man." Noise as a Public Health Problem (editor W. D. Ward), 765-776.

Rylander, R., Sorensen, S. Kajland, A (1972). "Annoyance Reactions from Aircraft Noise Exposure." Journal of Sound and Vibration, 24(4), 419-444.

Rylander, R., Sorensen, S., Alexandre, et al (1973). "Determinants for Aircraft Noise Annoyance - A Comparison Between French and Scandinavian Data." Journal of Sound and Vibration, 28(1), 15-21.

Rylander, R., Sorensen, S. (1973). "Aircraft Noise Determinants of the Extent of Annoyance Reactions." Proceedings of the International Congress on Noise as a Public Health Problem, W. D. Ward, ed. EPA Report Doc. 550/9-73, ONAC, 661-67.

Rylander, R. (1974). "Re-analysis of Aircraft Noise Annoyance Data Against the dB(A) Peak Concept." Journal of Sound and Vibration, 36(3), 399-406.

Rylander, R., Sorensen, S. (1974). "Annoyance and Aircraft Noise Exposure - Effects of Change in Exposure Level." Departments of Environmental Hygiene, University of Göteborg, National Environmental Protection Board (Sweden) and Division of Environmental Medicine, University of Geneva (Switzerland).

Rylander, R., Sorensen, S. (1976). "Community Reactions to Environmental Noise." International Congress, Turin, 7-10 June 1975. Man and Noise, p. 420-425. (G. Rossi and M. Vigone editions)

Rylander, R., Sorensen, S., Kajland, A. (1976). "Traffic Noise Exposure and Annoyance Reactions." Journal of Sound and Vibration, 47(2), 237-242.

Rylander, R., Sjostedt, E., Bjorkman, M. (1977). "Laboratory Studies on Traffic Noise Annoyance." Journal of Sound and Vibration, 52(3), 415-421.

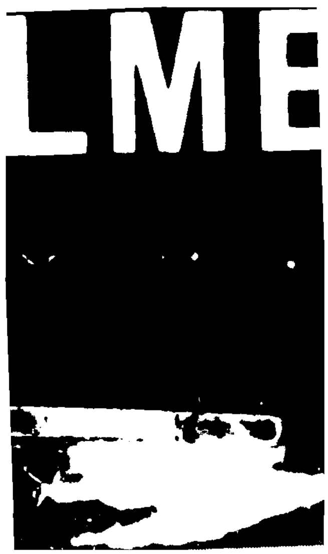
Rylander, R., Bjorkman, M., Ahrlen, Sorensen, S., Berglund, K. (1980). "Aircraft Noise Annoyance Contours: Importance of Overflight Frequency and Noise Level." Journal of Sound and Vibration, 69(4), 583-595.

Schomer, Paul D. (Nov. 1979). "The Growth of Community Annoyance with Loudness of Events and with Frequency of Occurrence of Events." Construction Engineering Research Laboratory Technical Manuscript N-83.

Schultz, T. J. (1974). Comments on "Determinants for Aircraft Noise Annoyance - A Comparison Between French and Scandinavian Dat" by R. Rylander, S. Sorensen, A. Alexandre and P. H. Gilbert, 1973, Journal of Sound and Vibration, 28, 15-21. Comments appear in: Journal of Sound and Vibration, 33(3), 369-371.

Schultz, T. J. (1978). "Synthesis of Social Surveys on Noise Annoyance." Journal of the Acoustical Society of America, 64(2), 377-405.

☆U.S.Government Printing Office: 1981 — 757-002/427


LME